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A METHOD TO FORECAST WINTERTIME INSTABILITY AND NON-LAKE EFFECT SNOW SQUALLS ACROSS NORTHERN NEW ENGLAND

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1. INTRODUCTION

During the late fall, winter, and early spring, large synoptic scale weather disturbances frequent the northeast corridor of the United States. As these storms pass to the north and east of New England, a west to northwest flow of colder air becomes established over the area.

Within this airmass it is common to observe the passage of a series of surface troughs or a secondary cold front, which may or may not be accompanied by positive vorticity advection at 500 mb. In any event, these features are usually associated with varying amounts of clouds, flurries, and even snow squalls.

Although the snow squalls are usually not as intense and prolonged as those experienced downwind of the Great Lakes, they still can significantly reduce the visibility and produce a couple inches of snow in a short time period, having a great impact on both aviation and road travel. At least several times a year, the mountainous areas of northern New England receive a significant snowfall as a result of persistent snow squalls in an unstable northwest flow. The technique presented in this paper uses the Nested Grid Model (NGM) low level temperature difference, boundary layer relative humidity, and an increase in the lifted index over a 12-hr time period to produce a Wintertime INstability inDEX (WINDEX). During a 3-year period, WINDEX was computed for almost 90 wintertime post-cold frontal trough passages. Relationships were established between WINDEX values and the potential for snowsqualls.

2. METHODOLOGY

Snow squalls in winter are similar in nature to thunderstorms in summer. Both are mesoscale convective cells driven by an unstable atmosphere, sufficient moisture in the boundary layer, and a lifting mechanism. To successfully forecast the occurrence of snow squalls, one has to quantify these 3 parameters.

In WINDEX, the temperature difference between the NGM T1-T5 layers is used to determine low level instability. The NGM boundary layer relative humidity (R1) is used to determine the amount of low level moisture available, and the increase in the NGM lifted index during a 12-hr period encompassing a trough or cold front passage is used to determine potential lift.

2.1. Instability

During the late fall and winter, cold outbreaks of arctic air across northern New England are associated with some degree of instability. The depth of this unstable layer is usually within the first 2 to 3 km of the surface. In forecasting lake effect snow squalls, Niziol (1987) quantified the instability as the difference in temperature (°C) between the surface water of the lake and 850 mb.

In this study, however, the goal is to forecast the potential for the development of snow squalls over land. One way to quantify the low level instability is to take the difference between the NGM layer 1 temperature (T1) on the NGM FOUS, and the temperature from model layer 5 (T5). The T1 temperature is the mean value taken from a layer which ranges from 1000 to 965 mb, while the T5 temperature is the mean value taken from a layer which ranges from 820 to 785 mb (McEwen, 1986). The maximum temperature difference between these layers would correspond to the dry adiabatic lapse rate. Poisson's equation was used to find the temperature difference necessary to achieve the dry adiabatic lapse rate for the extreme pressure surfaces of the T1-T5 layer. As shown in Appendix 1, this in turn was used to find the temperature difference for the dry adiabatic lapse rate for the average T1-T5 layer which was 17°C. This value was used to represent the greatest potential instability in roughly the first 2 to 3 km of the atmosphere. It is within this shallow layer that many of the snow squalls form over New England.

2.2. Moisture

Northern New England does not have an abundant moisture source immediately to its west as is the case in western New York. There is the expansive Atlantic Ocean to the east, but the predominant wind flow during snow squall events is from the west or northwest. Therefore, the limited moisture available for snow squall development in northern New England is generally through advection or from residual moisture after a recent storm.

Both the NGM mean relative humidity (R2) and the boundary layer relative humidity (R1) were examined for this study. However, as more events were documented, it became clear that the boundary layer relative humidity (R1) correlated better with the occurrence of snow squalls. This is reasonable when you consider that forecasters generally look at surface dew points and not necessarily the mean relative humidity between 965 and 473 mb, when determining the amount of moisture available for the formation of thunderstorms in the summer.

2.3. Potential Lift

Perhaps, the most difficult parameter to quantify is the strength of a lifting mechanism. The NGM 700 mb vertical velocity was first examined, but was found to be unrepresentative at times. The reason may be that most of the lift needed to generate snow squalls occurs below this level. Upon closer examination, it was found that a large increase in the NGM lifted index (LI) during the 12-hr period along and behind the passage of a trough or cold front, was better at determining potential lift for snow squalls.

This increase in the LI does not physically measure the lift of a parcel of air, but rather is a way to approximate the magnitude of the change in airmass at a location over a given time period. That is, a larger change in the LI could be viewed as a larger change in airmass. Therefore, the cold front or trough which ushered in this airmass change would likely have a greater discontinuity and low level lifting mechanism.

2.4 Data

To quantify these parameters, WSO Concord (CON) surface aviation observations were examined during the period November through March for the years 1989-1992. A snow squall for this study was defined by those instances where visibility was reduced to less than 3 miles by short duration snowfall. This could also be termed a snow shower, but the purpose here is to differentiate between flurries, which by definition are trace events, and those events that may result in accumulating snow. A visibility of less than 3 miles is also important in aviation forecasting, since this would constitute instrument flight rules (IFR) conditions.

Aviation observations for the time period up to 48 hours after a period of observed synoptically-induced (large scale) precipitation were carefully screened to find short duration snowfall. The amount of instability cloud cover (below 7000 feet) was also noted based on the following classification scheme: (1) clear; (2) scattered; (3) broken; (4) overcast; and (5) snowsquall. Note: a number which is follow by "+" means the clouds varied between two categories. (e.g., 2+ would mean that a sky cover was scattered, but sometimes broken.) An s- was added to the end of a sky cover if flurries were observed.

There were nearly 90 events examined for this study of which about 30 had flurries or snow squalls. The time of day an event was observed dictated which NGM model run was used to collect the necessary data. In general, a morning event was documented using the 1200 UTC initial data. The 6-hr forecast was used for afternoon events and the 0000 UTC initial data was used for evening events. The increase in the lifted index was determined by taking the lowest LI around the time of the event and subtracting it from the LI which was forecast by the NGM 6 and 12 hours later. The larger increase in LI was then used. This will occasionally be referred to as the 12-hr change in LI throughout the rest of this paper.

3. RESULTS

After all the events were archived and the data was examined, the T1-T5 temperature difference, the increase in LI during a 12-hr period, and the boundary layer RH (R1) were plotted on 2 graphs. Figure 1 shows the 12-hr change in LI versus the T1-T5 temperature difference where R1 > 50%. Figure 2 is the same, but for R1 < 50%. From the data and corresponding graphs, cutoff values were observed to be critical for the occurrence of snow squalls.

3.1. Instability

The term instability, as used in this paper, pertains to the difference in temperature between the NGM T1-T5 layer. The larger the difference, the steeper the lapse rate, and the greater the instability in the low layers. For this study the following terms are defined in relation to the T1-T5 difference:

1. Stable --- less than 10°C
2. Potentially Unstable --- 10 to 13°C
3. Unstable --- 14 to 17°C

It is interesting to note that most snow squall events in Concord took place when the T1-T5 temperature difference was 10°C or more and R1 > 50%.

3.2. Potential Lift

An increase in the NGM lifted index of 8 or greater during a 12-hr period, along and behind a surface trough or cold front, appeared to be critical to the development of snow squalls in an unstable or potentially unstable environment. However, this increase in lifted index is only to be used for those troughs and cold fronts which move in a continuous fashion. If no trough or cold front was present then variable clouds and flurries were sometimes observed.

In some cases, troughs that were nearly stationary produced snowsqualls or heavy snow showers regardless of the change in lifted index when there was sufficient moisture and instability available. In this situation, convergence played a greater role than a change in airmass to produce lift.

Additionally, although snow squalls are mesoscale in nature, synoptic-scale positive vorticity advection (PVA) at 500 and 700 mb, and positive vertical velocity fields were observed to enhance the intensity and duration of snowsqualls.

3.3. Moisture

Through close examination of the data, a boundary layer R.H. of 50% or greater was determined to be necessary for the formation of snow squalls. A boundary layer R.H. less than 50% generally resulted in clear skies or scattered clouds, except when the T1-T5 temperature difference indicated an unstable atmosphere, in which case snow flurries were occasionally noted.

4. WINDEX

Based on a scatter diagram of the T1-T5 temperature spread vs. 12-hr change in LI, for a R1 > 50%, WINDEX (Fig. 1) was simplified into a contingency diagram. Figure 3 shows this WINDEX diagram divided into 5 parts that represent different potential weather conditions.

Snow squalls are most likely to occur in AREA A located on the WINDEX diagram. This area represents where the greatest instability, moisture, and potential lift is present. In general, snow squalls are likely when there is an approaching surface trough or cold front, the instability is 10°C or greater, R1 is greater than 50%, and the increase in LI is 8 or greater during a 12-hr period along and behind the discontinuity.

AREA B represents an area where the low level is unstable (T1-T5 spread 14°C or greater) and there is sufficient moisture for "airmass" type of flurries and snow showers. Even though there may not be a lifting mechanism to cause snow squalls, the airmass is moist and unstable enough to produce flurries and snow showers during the afternoon, after some solar heating has taken place. This is analogous to the airmass type showers and thundershowers that develop in an unstable atmosphere in summer.

A few flurries are occasionally observed in AREA C where the airmass is potentially unstable (T1-T5 difference is 10 to 13°C) and there is sufficient low level moisture. However, a lifting mechanism is generally lacking for organized snow shower or snow squall activity.

Within AREA D of the WINDEX diagram, the T1-T5 temperature difference is less than 10°C, which is usually too stable for flurries. However, flurries were occasionally observed when there was a surface trough, cold front, or significant 500 mb PVA moving through the area.

AREA E represents where the low levels are usually too stable for flurry or snowsquall activity.

WINDEX was also used in an attempt to predict the extent of instability cloudiness during the daytime. Although the results were less conclusive, there was a definite correlation between increased cloudiness and boundary layer relative humidity greater than 50%. More study is planned in this area, however, the results thus far can possibly be used as guidelines.

4.1 Other Important Considerations

a) All of the data used in this study was from Concord, New Hampshire. This area is located in a downslope region of the state. Higher terrain lies to the west and north of this site. When winds are from the west-northwest the air tends to sink and dry out. Since the general flow in snow squall events is from the west-northwest, snow squalls are usually not as intense and prolonged as those observed over the higher terrain of Vermont, New Hampshire and Maine.

b) WINDEX is not a tool to forecast the snow accumulation from snow squalls. In general however, snow squalls in Concord were usually short in duration and produced less than an inch of snow.

c) The heaviest snow squall events were usually observed in the mountains of northern New England. They occurred when 500 mb PVA accompanied a frontal system, which encountered an airmass that was potentially unstable with a boundary layer RH of 80% or greater. The heaviest snowfall seemed to occur along and just south of the vorticity maximum track. During one event, snowfall amounts varied from 1 to 3 inches, with up to 5 to 10 inches in the more favorable orographic locations. The following section describes that event.

5. A CASE STUDY USING WINDEX

During the evening of March 17, 1992, a surface cold front was predicted to move southeast across northern New England (Fig. 4). At 500 mb, a vorticity maximum was forecast by the NGM to move across northern Vermont, extreme northern New Hampshire, and into the western mountains of Maine (Fig. 5). The NGM boundary layer moisture (R1) was predicted to be 80%

or greater throughout much of New England (Fig. 6). The forecast issued for northern New England was for scattered evening flurries, then clearing based on the NGM mean relative humidity (R2) that was generally less than 70% across the area (Fig. 7).

In retrospect, WINDEX would have provided important guidance that snow squalls could be expected to develop along the front and move across much of northern New England. Figure 8 shows the 1200 UTC NGM FOUS for several sites in the Northeast. In addition, the variables used for WINDEX are shown. Five out of 6 sites were located in AREA A of WINDEX which indicated snow squall development was likely. Albany, NY (ALB) was a bit more stable in the low levels and was located in AREA D of WINDEX, which corresponds to "flurries possible with frontal passage". In fact, with the vorticity maximum at 500 mb moving across extreme northern Vermont, northern New Hampshire, and the western mountains of Maine, snow accumulations in those areas seemed to be likely.

As illustrated by Figure 9, 2-6 inch accumulations fell over the northern mountains of Vermont, New Hampshire and Maine. Much of the rest of the region received a dusting to an inch from the snow squall activity.

6. CONCLUSION

The Winter INstability inDEX, or WINDEX, has proven to be a quick and simple tool to use in forecasting the potential for snow squalls over northern New England during the winter months.

As found in this study, snow squalls are likely to form if there is an identifiable surface discontinuity such as a trough or cold front forecast to move in a continuous fashion across the area. In addition, during the study period, the following were found to be necessary for the development of snow squalls:

1) The T1-T5 temperature difference is 10°C or greater.

2) The boundary layer RH (R1) is > 50%.

3) The LI increases by 8 or greater during a 12-hr period.

One word of caution, WINDEX is only as good as the NGM's forecast is accurate. The NGM sometimes will vacillate from run to run which will give the forecaster reduced confidence in WINDEX. Clearly this is not a problem with WINDEX, but rather it is the inherent inconsistency the NGM model may occasionally exhibit. However, it has always been a challenge to forecast the extent of instability in a cold west to northwest flow during the winter months. Hopefully, WINDEX will give the operational meteorologist more confidence to differentiate between a forecast of snow squalls or just scattered flurries.

ACKNOWLEDGMENTS

I would like to thank Steve Nogueira, Meteorologist Intern WSO Concord NH, for his constructive criticism and ideas while helping me turn WINDEX into a useful forecast tool. Thanks to Fred Ronco, DMIC WSFO Portland ME, for listening to my ideas and encouraging me to pursue this method of forecasting wintertime instability. Also, a thank you to Walt Drag, WSFO Boston, MA, who through state forecast discussions and coordination with WSFO's, promoted the use of this study.

REFERENCES

Niziol, T. A., 1987: Operational forecasting of Lake Effect snowfall in western and central New York. *Wea. and Forecasting* 2, 310-321.

McEwen, L., 1986: NWSTC Numerical Guidance; RAFS FOUS. Available from the NWS Training Center, 617 Hardesty Ave., Kansas City, MO 64124, 11pp.

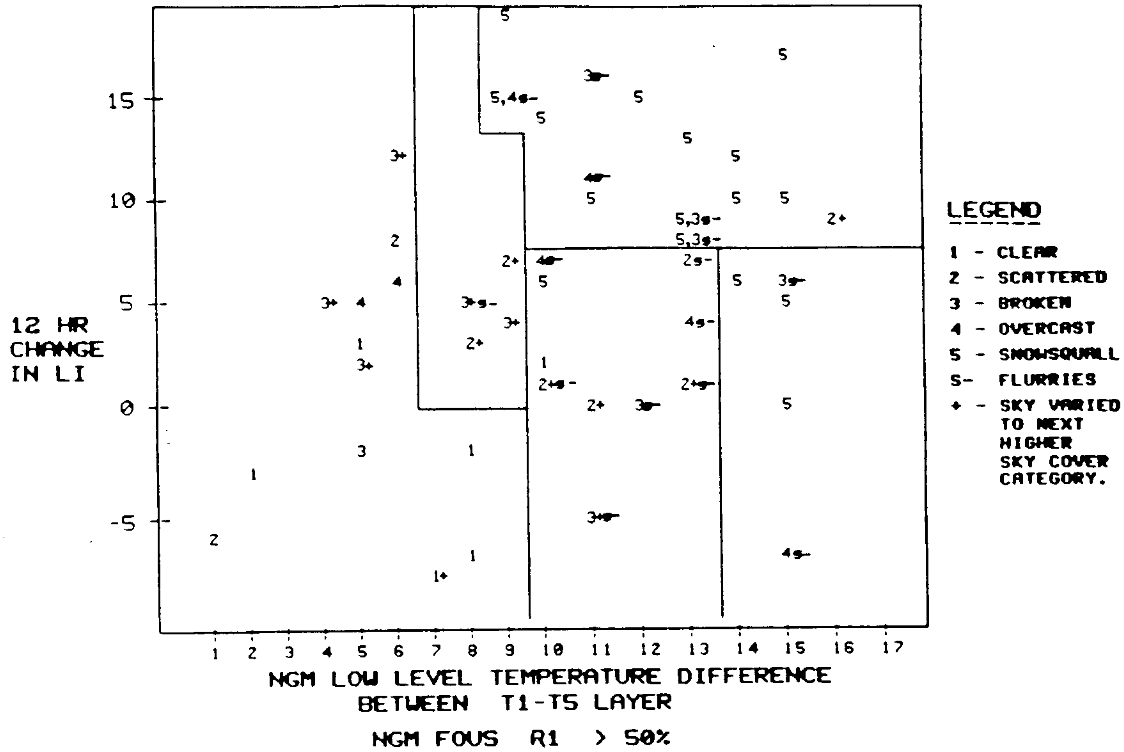

Figure 1. November 1989 through March 1992, WSO Concord, 12-hr change in LI vs. the NGM T1-T5 temperature difference. Boundary layer RH (R1) > 50%.

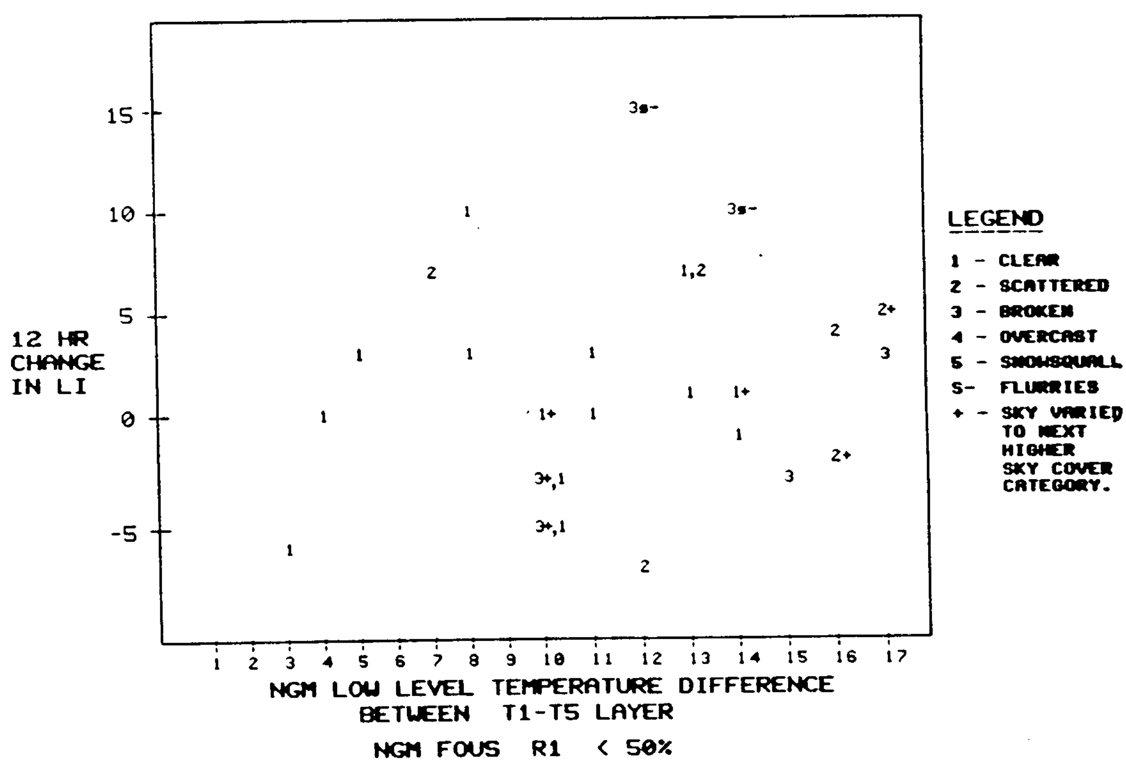

Figure 2. November 1989 through March 1992, WSO Concord, 12-hr change in LI vs. the NGM T1-T5 temperature difference. Boundary layer RH (R1) < 50%.

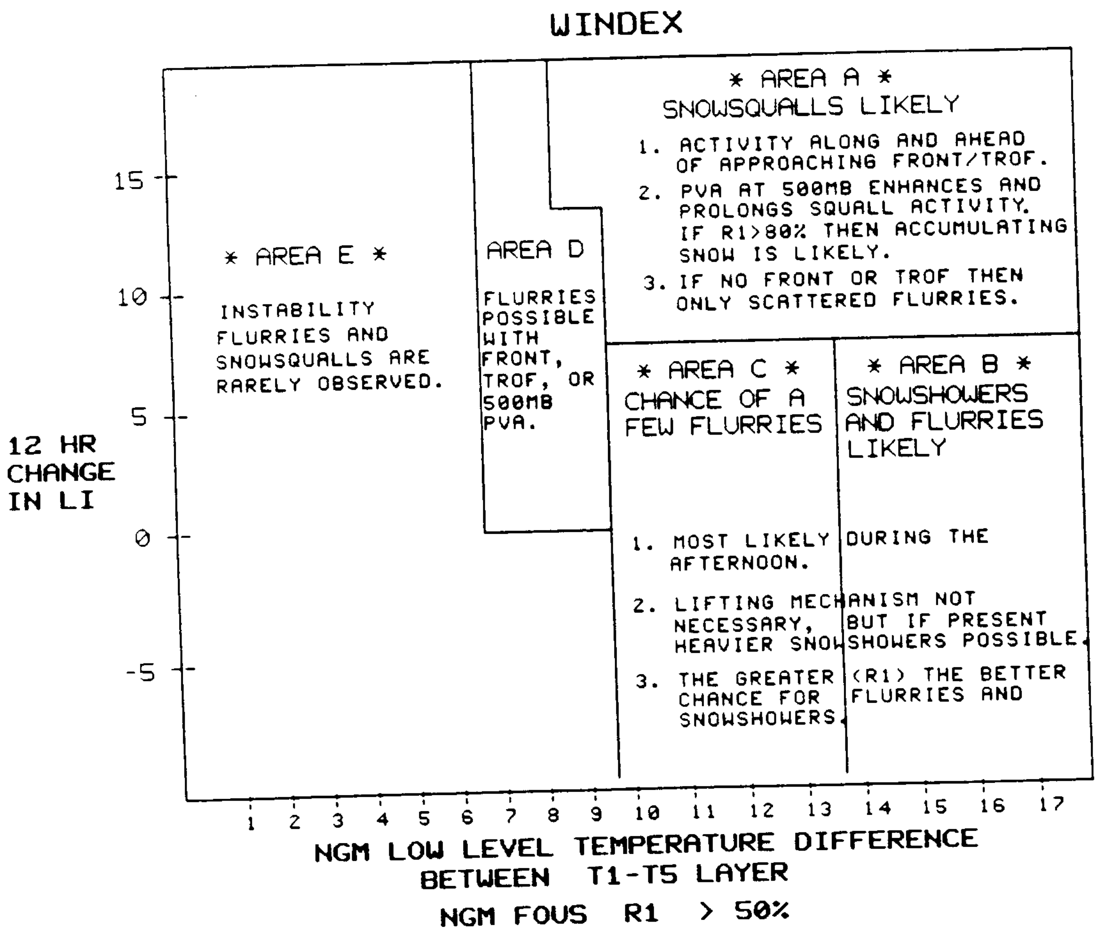

Figure 3. November 1989 through March 1992, WSO Concord graphical representation of WINDEX.

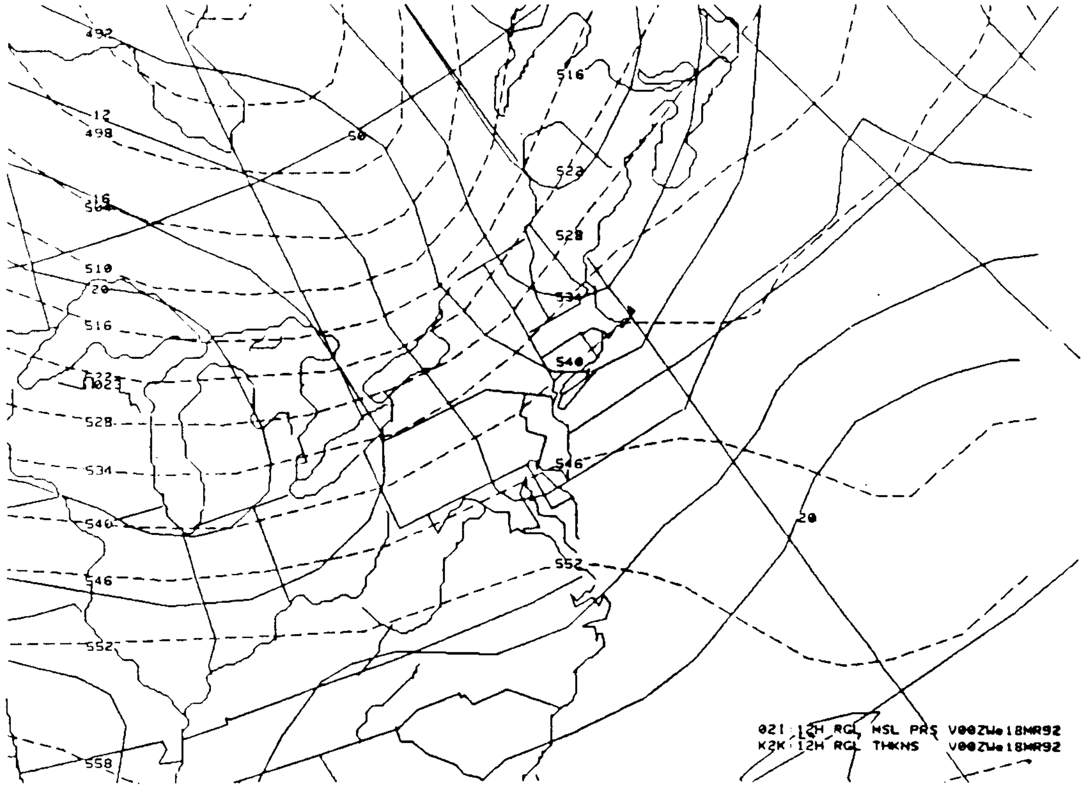

Figure 4. 0000 UTC, March 18, 1992. NGM MSL pressure analysis and 1000-500 mb thickness.

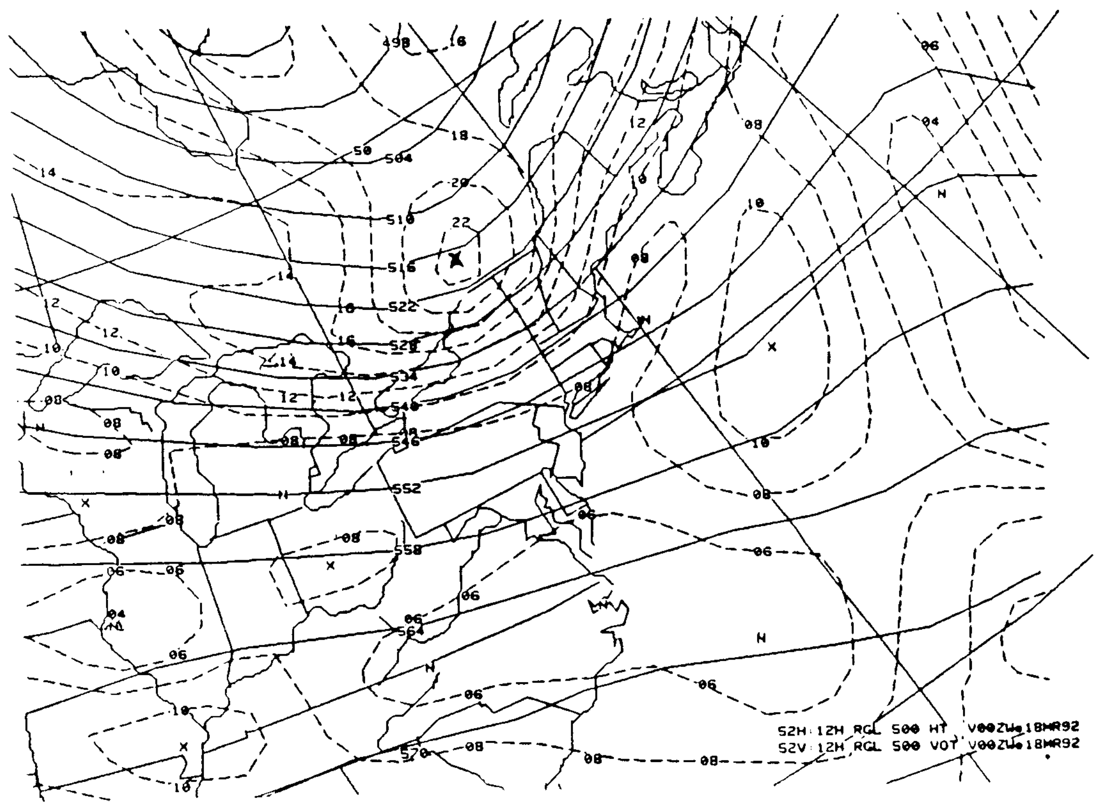

Figure 5. 0000 UTC, March 18, 1992. NGM 500 mb height analysis and vorticity.

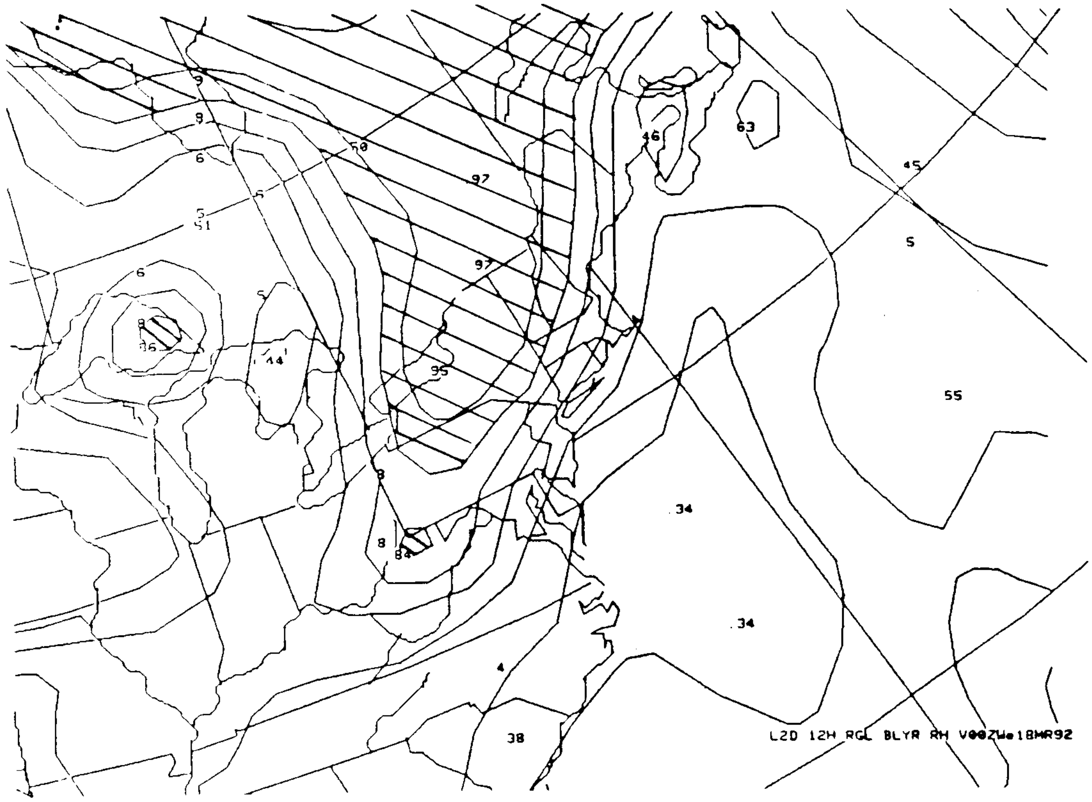

Figure 6. 0000 UTC, March 18, 1992. NGM boundary layer relative humidity. Hatched area denotes RH > 80%.

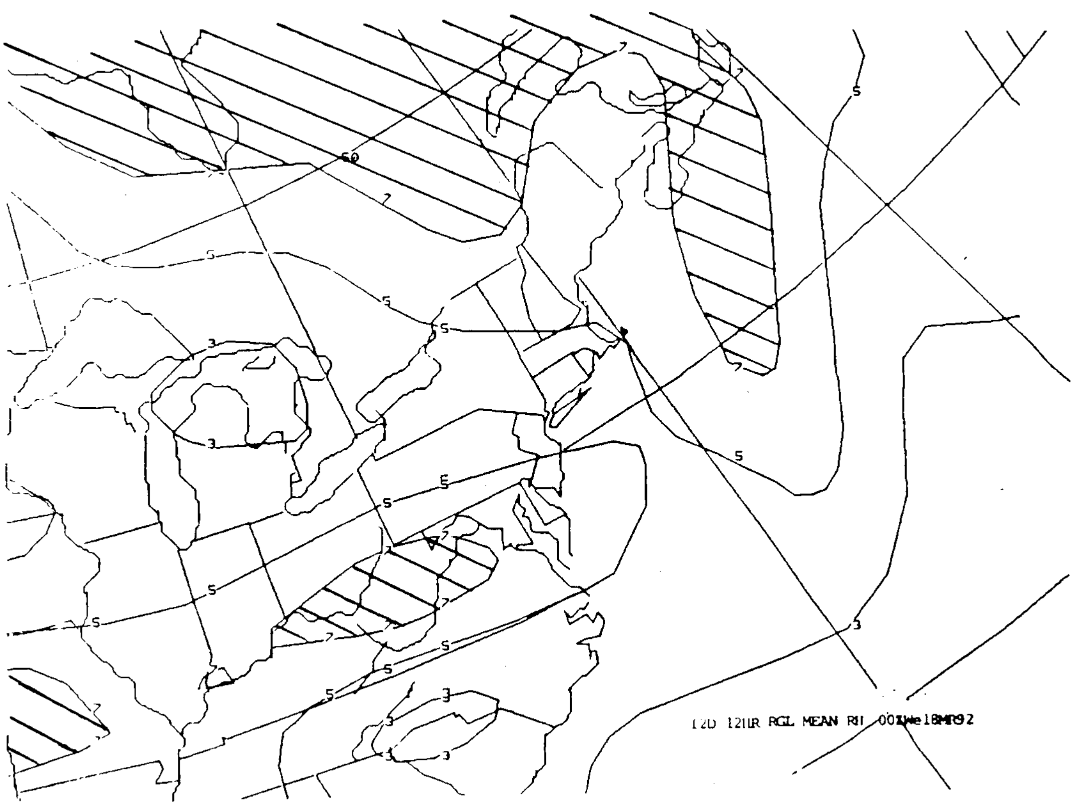

Figure 7. 0000 UTC, March 18, 1992. NGM 1000-500 mb mean relative humidity. Hatched area denotes RH > 70%.

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NGM FOUS GUIDANCE
OUTPUT FROM MAR 17 92 12Z

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
ALB//487067 02014 132418 35979794
06000736345 -2712 072414 37029695
12000084428 -0412 072822 33009692
18000052827 -4921 163119 25958989
24000073334 -3519 213113 23918692

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
PWM//305069 -2219 122420 32969893
06000497267 -1614 062417 35019693
12000725321 03011 022623 32039790
18000663513 -3017 093125 20989184
24000582619 -3221 163121 16918680

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
BGR//446460 00819 112320 29969490
06000468353 -1318 052317 32009591
12000695717 03410 012520 28029680
18002764700 -3113 063025 16989182
24000523409 -3521 133122 09900383

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
BTV//740144 03114 092416 31959391
06000956630 -0313 042414 31009590
12003965400 00311 052820 22999306
18002983214 -4119 153118 14918683
24000773420 -4820 203015 13080186

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
CAR//528732 01817 082216 23919187
06000646929 01215 012212 24989187
12000016514 02800 992615 18999383
18002916306 -1912 033019 07938700
24000025206 -2421 103010 00057070

TTPTTR1R2R3 VVVLI PSDOFF HHT1T3T5
CON//315270 -1917 132420 33969794
06000667365 -1814 062415 37029694
12000765023 01711 042723 33039791
18000733018 -3419 123122 23979180
24000652027 -3521 103117 19918490
```

WINDEX PARAMETERS

	T1-T5	R1	12HR LI	AREA
ALB	8	88	9	D
BTV	14	96	9	A
PWM	13	72	10	A
CAR	16	81	13	A
BGR	16	69	11	A
CON	12	76	10	A

WEATHER OBSERVATIONS

CONCORD

```
SP 2300 -X M10 BKN 40 OVC 2SW- 3220G32/978/S2
SP 2317 W6 X 3/8SW 3219G32/979
SP 2323 W2 X 1/4SW+ 3221G29/979
SP 2330 10 SCT E45 OVC 5SW- 3217G31/980/WSHFT 05
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ALBANY

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SA 2250 30 SCT M40 BKN 10SW- 149/34/21/2921G33/996
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Figure 8. 1200 UTC, March 17, 1992. NGM FRHT FOUS guidance and corresponding WINDEX parameters.

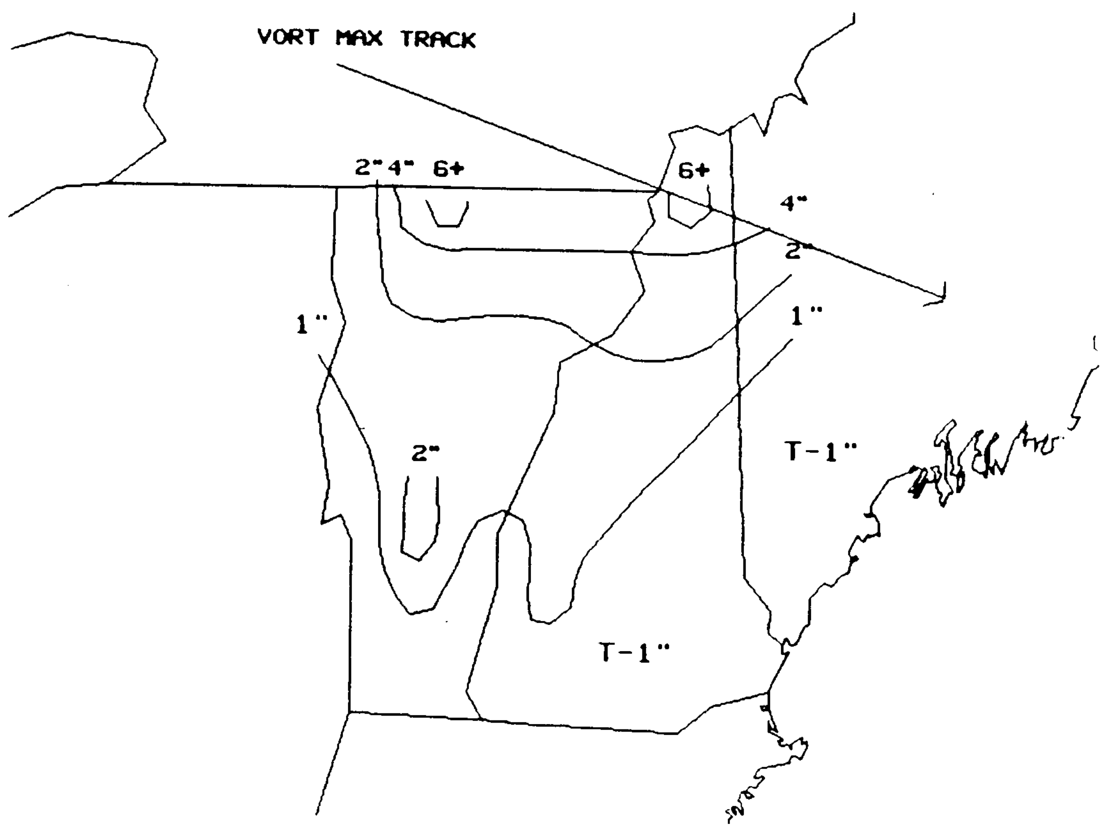

Figure 9. Snowfall amounts from snowsquall event of March 17/22Z-18/04Z '92.

APPENDIX A

```
  |              --------------        755 mb
P |                                              (T5 layer)
R |              --------------        816 mb
E |
S |  ( T1-T5 layer )
S |
U |
R |              --------------        965 mb
E |                                              (T1 layer)
  |              --------------       1000 mb
  |________________________________________________
```

T1 LAYER 1000 - 965 mb
T5 LAYER 816 - 755 mb

THEN:
SMALLEST (T1-T5) LAYER - 965 - 816 mb
LARGEST (T1-T5) LAYER - 1000 - 755 mb

USING POISSON'S EQUATION TO FIND THE DRY ADIABATIC LAPSE RATE FOR EACH LAYER, ASSUMING T1=273K AT T1 PRESSURE LEVEL AND SOLVING FOR T5 TEMPERATURE:

$$T = T_o * (P/P_o)^{(R/mCP)}$$

T = T5 temperature
T_o = T1 temperature
P = T5 pressure level
P_o = T1 pressure level
(R/mCP) = .286

FOR SMALLEST (T1-T5) LAYER: $T = 273^\circ K * (816/965\ mb)^{.286}$
$= 260^\circ K = -13^\circ C$

THUS: THE DRY ADIABATIC LAPSE RATE = T1 - T5
$= 0^\circ C - (-13^\circ C) = 13^\circ C$

FOR LARGEST (T1-T5) LAYER : $T = 273^\circ K *(755/1000\ mb)^{.286}$
$= 252^\circ K = -21^\circ C$

THUS: THE DRY ADIABATIC LAPSE RATE = T1 - T5
$= 0^\circ C - (-21^\circ C) = 21^\circ C$

FINALLY: THE TEMPERATURE DIFFERENCE NECESSARY FOR AN ADIABATIC LAPSE RATE FOR THE AVERAGE T1-T5 LAYER IS:

(ADIABATIC LAPSE RATE FOR (SMALLEST + LARGEST) LAYER)/2 =

$(13^\circ C + 21^\circ C) / 2 = \underline{17^\circ C}$